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FOREIGN TECHNOLOGY DIVISION

THE ALTERNATING EFFECT OF SEA BREEZE AND BORA

by

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THE ALTERNATING EFFECT OF SEA BREEZE AND BORA

Berislav Makjanic

Abstract.

In an investigation of the sea breeze in Split on the east coast of the Adriatic it was found that during the year 1956 in $22^{\circ}/_{\circ}$ of the cases the sea breeze occurred simultaneously with an upper flow directed from land to sea. The upper flow was defined as an average wind between 1600 and 3000 m above MSL. It was possible to arrive at the wind profile of the "pure" sea breee by vector subtraction of the theoretically derived profile of the general wind from the actual wind profile for the days when general wind from the land and the sea breeze were superimposed. This sea breeze profile is in good agreement with the theoretical one. It was found at the same time that the Erkman spiral, although two-layered, does not give a good representation of the actual Bora. Therefore an empirical average

bora profile was derived from five days with a strong bora. In this case agreement of the theoretical and empirical "pure" sea breeze profile was even better.

It is perhaps strange that one would speak about the sea breeze at a conference for alpine meteorology because it is a phenomenon which is characteristic for sea coasts, particularly for coasts of the warmer seas. Our country has the advantage, at least for meteorologists, that here the southeastern spurs of the Alps and the Adriatic Sea come into close contact. On a large part of the east coast of the Adriatic the slopes of the Dinaric Alps rise abruptly out of the sea to an altitude of 1500 m and higher. Such a coastal configuration causes a great complication of all meteorological phenomena. It can happen that the coastal circulation (land- and sea breeze), slope upcurrent, and the general flow can appear simultaneously on the synoptic scale. In addition there are local effects which are brought about by the irregularities of the coast line and by the terrain configuration near the coast. These effects complicate the circumstances even more.

In this report it is my intention to represent some results which have been gained in a theoretical and empirical study of the sea breeze. In the theoretical part of this study the system of

differential equations of the sea wind was solved. This system differs from the known system of F. Defant (1950) in that here the turbulence of the instantaneous transport in the atmosphere is taken into account instead of the the simpler assumption of Guldberg-Mohnschen friction as in Defant's work. Connected with that, the boundary conditions for the solid boundary (the Earth's surface) were improved. In this manner it was possible to obtain two models of the sea breeze: one with a disappearing wind on the solid boundary and the other with a two-layered atmosphere. In the latter case the analytical solution was possible for the upper layer (above 100 m). The two-layer solution gave a better approximation of the actual sea breeze.

During the attempt, using high-altitude wind measurements in Split in the year 1956, to verify the theory one discovered that the sea breeze was almost always superimposed on a general flow on the synoptic scale. It was therefore necessary to find a method according to which one could separate the sea breeze from the general flow and get it in pure form which would then be comparable with the theoretical sea breeze.

It would be simplest to assume that both flows as well as the sea breze and the general flow have no effect on each other, i.e., that these flows add to each other according to the principle of

superposition of movements. Of course this is true only in the first approximation but there were no bases for the complex assumption since on one hand the general flow was obtained as stationary and on the other hand during derivation of the theoretical sea breeze the advective terms of the acceleration were disregarded.

Accordingly, one proceeded as follows. All of the high-altitude wind data on the days with sea breeze was divided into four groups depending on the wind direction at an altitude above 1600 m. During this analysis it was noted that the wind direction in the layer from 1600 to 3000 m was rather constant. Therefore the middle wind in this layer was taken as the average general flow in each of the four groups named above. These four groups were:

a) general flow from the land out of the NE,

b) general flow from the sea out of the SW

c) general flow along the coast from the SE

d) general flow along the coast from the NW.

In all 78 sea-breeze days were examined. On 17 days or 22°/, of the cases there was a sea breeze with a general land flow.

The wind distribution according to altitude on these days at 1600 is shown in Fig. 1 by the components u (perpendicular to the coast) and v (parallel to the coast). One sees that in the middle the general flow above 1600 m has a force of u=5 m/s and v=0 m/s.

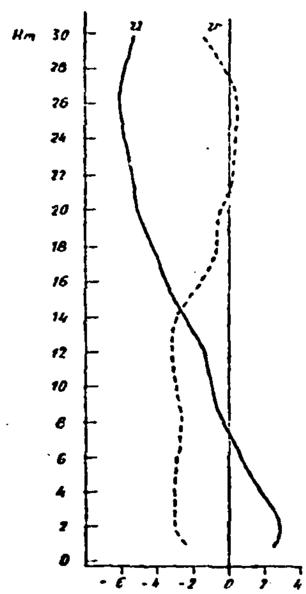

Fig. 1. True average wind profile at 1600 on 17 days with sea breeze and land flow (Split, 1956).

With these rounded values for the velocity of the geostrophic

wind from the corresponding formulas one can obtain the altitude distribution of the general flow under the assumption that the friction is turbulent and that the atmosphere is two-layered (in numerical calculations the thickness of the lower layer was 100 m). This altitude distribution is shown in Fig. 2. If one now applies the principle of the superposition of movements and subtracts the profile of Fig. 2 from the profile of Fig. 1, one then obtains the pure sea breeze. The extent to which this procedure is successful can be seen in Fig. 3. The same figure also shows the altitude distribution of the theoretical sea breeze but only for the case when the maximum land-sea temperature difference is 1°C. As one can see the agreement, particularly the qualitative agreement, is satisfactory.

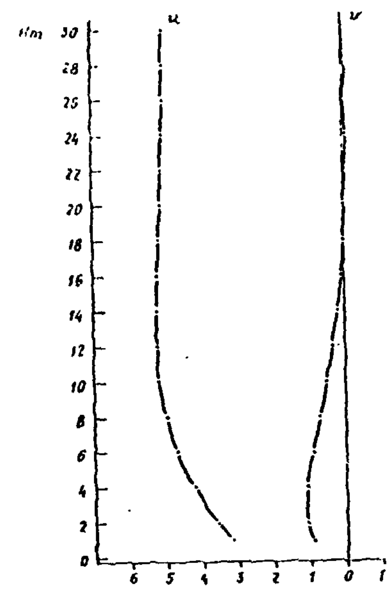

Fig. 2. Theoretical wind profile of a steady-state flow.

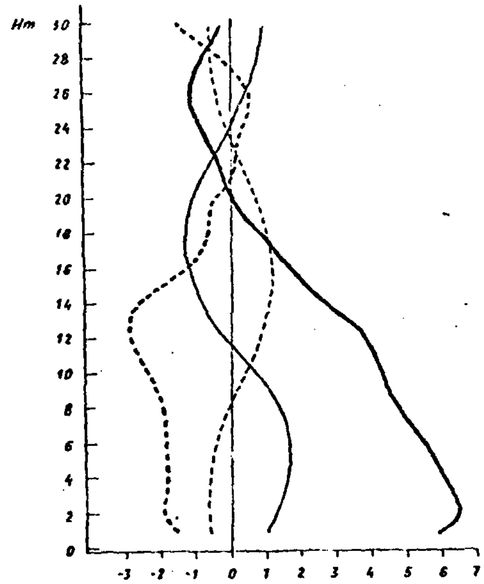

Fig. 3. Semi-empirical (thick lines) and theoretical (thin lines) sea breeze profile.

In Split, because of the terrain configuration, the general flow usually has a catabatic character, i.e., we are almost always dealing with a bora-type wind. Whether this catabatic wind sometimes has a character of the foehn has not yet been studied. Because of the orographic effects one can expect that the general flow will not follow the assumed wind profile. In order to show this, from the observations made in 1956 nine pilot balloon launches within five days were chosen, and to be sure, on days when in Split the bora blew

the entire day and the bora layer was at least 3000 m. For these days we calculated the average wind profile as in Fig. 4. One sees that significant deviations of this profile from the theoretical profile in Fig. 2 occur.

If one now converts this true bora profile, insignificantly smoothed, to the value of the geostrophic wind of u=5 m/s and then subtracts from the true wind profile for the sea-breeze days with a general land flow, then one obtains the profile of the pure sea breeze in Fig. 5.

The sea breeze profile in Fig. 5 is purely empirical and shows some differences as compared with the profile of Fig. 3. which is designated as semi-empirical.

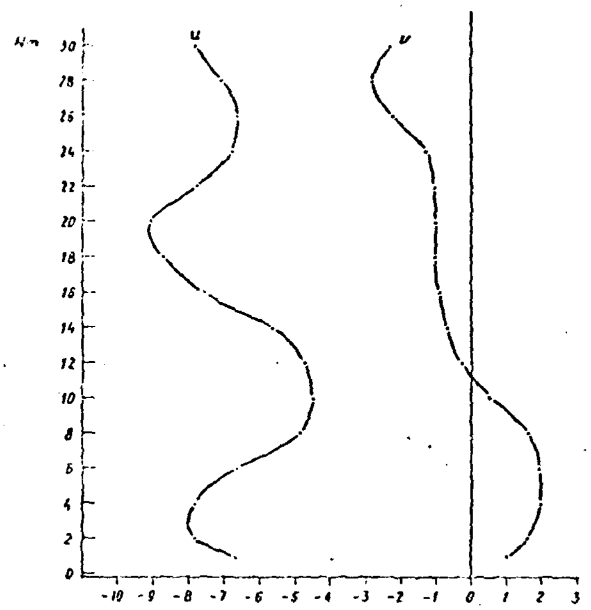

Fig. 4. True average bora profile for 5 days (Splt 1956).

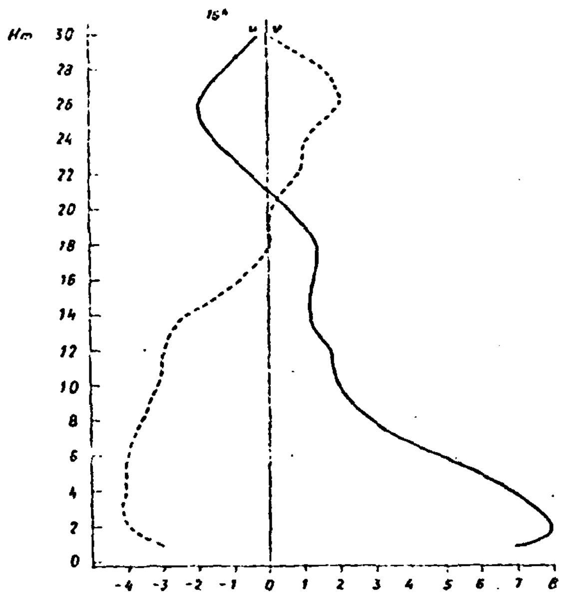

Fig. 5. Sea breeze profile as the difference of the profile of the true wind (sea-breeze days) and the bora.

If one does not take the sea breeze into account, then concerning the bora, one can say that its profile is not well represented by the vertical distribution of the steady-state flow. The grounds for this are doubtless to be sought in the facts that first of all the bora is a catabatic wind and second that it is not steady-state. One can also conclude from this that there are summer days when morning (around 0700) and evening (around 2100) the bora blows with a force of more than 10 m/s and in the course of the day a

weak sea breeze (1-2 m/s) prevails. The sea breeze could not prevail if the bora velocity remained the same during the day as in the morning and evening. It must therefore be smaller during the day.

This brief sketch of the relationships between the sea breeze and the bora resulted as a byproduct of a study of the sea breeze. I am of the opinion that it can be advantageous to make the readership familiar with these results although they are still only the preliminary steps to an understanding of the relationships of these two local meteorological phenomena whose relationships have perhaps not been given sufficient attention.

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